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Land Condition Trend Analysis Data: Power Analysis

by
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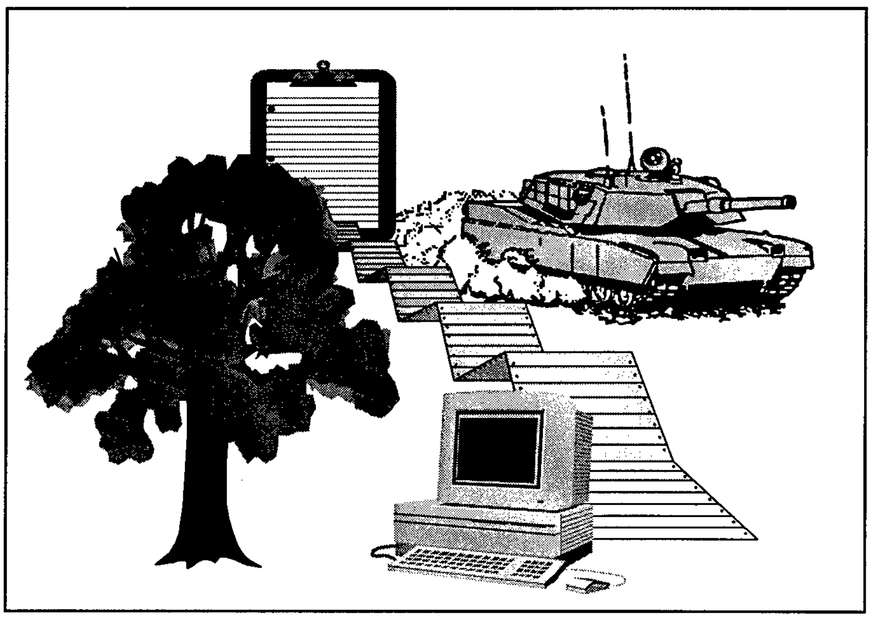

The Land Condition Trend Analysis (LCTA) program is the Army's standard for land inventory and monitoring, employing standardized methods of natural resources data collection, analyses, and reporting designed to meet multiple goals and objectives. LCTA data has been used to characterize installation natural resources, evaluate the effects of Army multiple use demands on training lands, ground-truth remote sensed imagery, and as a source of data for land based carrying capacity modeling efforts. A critical element of many of these applications is the ability of LCTA data protocols to detect changes in installation natural resources.

This report presents results of a study that used power analysis techniques to evaluate the ability of LCTA data collection protocols to detect changes in installation resources. The use of information and techniques presented in this report should increase land managers' confidence in conclusions drawn from studies using LCTA data by providing the information necessary to adequately judge the strength of evidence from those studies.

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13. ABSTRACT (Maximum 200 words)

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Foreword

This study was conducted for Office of the Directorate of Environmental Program (DAIM), Assistant Chief of Staff (Installation Management) (ACS(IM)) under Project 4A162720A896, "Environmental Quality Technology;" Work Unit EN-TL6, "Integrated Natural and Cultural Resources Data Analysis." The technical monitor was Dr. Victor E. Diersing, DAIM-ED-N.

The work was performed by the Natural Resource Assessment and Management Division (LL-N) of the Land Management Laboratory (LL), U.S. Army Construction Engineering Research Laboratories (USACERL). The USACERL principal investigator was Alan B. Anderson. Dr. David J. Tazik is Acting Chief, CECER-LL-N, and Dr. William D. Severinghaus is Operations Chief, CECER-LL. The USACERL technical editor was Agnes E. Dillon, Technical Resources.

COL James T. Scott is Commander and Dr. Michael J. O'Connor is Director of USACERL.

Contents

List of Tables and Figures

Tables

Figures

1 Introduction

Background

Natural resources monitoring is an essential part of any attempt to use natural resources wisely. Monitoring provides a source of feedback to land managers about the results of alternative land use strategies. The U.S. Army Land Condition Trend Analysis (LCTA) program was developed at the U.S. Army Construction Engineering Research Laboratory (USACERL) under the sponsorship of the U.S. Army Engineering and Housing Support Center (USAEHSC) as a means to inventory and monitor natural resources on military installations. LCTA uses standard methods to collect, analyze, and report natural resources data (Diersing et al. 1992) and is the Army's standard for land inventory and monitoring (Technical Note [TN] 420-74-3). Over 50 military installations and training areas in the United States and Germany have begun or plan to implement LCTA.

The LCTA program was designed to meet the needs of natural resources management and land stewardship on military installations (Tazik et al. 1992). LCTA uses information on topographic features, soil characteristics, climatic variables, vegetation, and wildlife resources to characterize an installation's natural resources. The information is intended to assist installation managers with making decisions on best use of land, scheduling of military activities, protection of threatened and endangered species, and long-term environmental planning. The information also provides Army personnel at all levels with standardized natural resources inventory information for installations across the continental United States and overseas. Specific objectives of LCTA are to:

- characterize installations' natural resources
- implement standards for collection, analysis, and reporting of acquired data that enable compilation and reporting of these data Army-wide
- monitor changes in land resource condition and evaluate changes in terms of current land uses
- evaluate the capability of land to meet the multiple-use demands of the U.S. Army on a sustained basis
- delineate the biophysical and regulatory constraints on uses of the land

- develop and refine land management plans to ensure long-term resource availability (Tazik et al. 1992; U.S. Department of the Army 1996; U.S. Department of the Army 1991).

An independent review panel of technical specialists (TN 420-74-3) concluded that the LCTA field methods were technically sound and that the data had broad application for land managers and Army trainers.

LCTA data sets currently exist for over 40 installations and contain 1 to 10 years of monitoring data. Considerable time and money has, and continues to be, devoted to the monitoring program. These efforts may be wasted if there is little chance of detecting anything but catastrophic changes or if the sampling intensity is in excess of what is required (Bernstein and Zalinski 1983; Peterman 1990a; Peterman 1990b; Peterman 1989). Considerable effort also has gone into analyzing and interpreting trends in the data as well as using the data for other purposes (Price et al 1995; Bouman and Shapiro 1994; Ribansky Draft; Warren and Bagley 1992; Wu and Westervelt 1994; Shaw and Diersing 1990; Trumbull et al. 1994; U.S. Army Concepts Analysis Agency 1996; Shaw and Kowalski 1996; Diersing et al. 1988; Shaw et al. 1990; Shaw and Diersing 1989; Senseman et al. 1996). LCTA data summaries have been incorporated into National Environmental Policy Act (NEPA) documentation (Schreiber et al. Draft; Balbach et al. 1994; Chawla et al. 1994; Fort Lewis, Washington 1994; Louis Berger and Associates 1994).

Although the data have been collected and summarized, little is known about the magnitude of the trends that can be detected. A recent report commissioned by the National Science and Technology Council (NSTC) for the White House criticizes U.S. field stations in general for not providing consistent, comparable, and statistically valid pictures of trends in the nation's biota (National Science and Technology Council 1995). Specific concern about the ability of the LCTA monitoring protocols to detect change have been expressed by installation natural resources personnel. In fact, methods to assess the effectiveness of Army natural resource inventory and monitoring programs is one of the Integrated Training Area Management (ITAM) program user requirements identified by the Office of the Deputy Chief of Staff for Operations and Plans (ODSCOPS) (U.S. Department of the Army 1996).

Power analysis is a statistical technique useful in quantifying the ability of a monitoring program to detect change in the monitored resource. The literature is filled with papers recommending an increased use of power analysis techniques in the design and analysis stages of controlled studies and monitoring programs (Toft and Shea 1983; Rotenberry and Wiens 1985; Hayes 1987; Peterman 1990a; Peterman 1990b). Power analysis techniques have not been used with existing installation

LCTA vegetation and disturbance data. However, investigators have successfully applied these techniques to LCTA wildlife protocols (Rice et al. 1995; Rice and Demarais 1995; Hayden and Tazik 1993), LCTA line transect methodology (Mitchell et al. 1994; Brady et al. 1995), and other military installation monitoring efforts, including Golden-cheeked Warbler studies at Fort Hood, Texas (D.K. Niven, 1994, unpublished report). The use of power analysis techniques in these studies has proven useful in evaluating current data collection methods and providing insight into the effects of modifications to those methodologies.

Some reasons power analysis techniques are not commonly used with LCTA data may be because installation personnel are not be aware of the consequences of Type-II errors or of procedures to conduct power analysis, or that the results of power analysis can strengthen statistical inferences from the data. However, power analysis techniques require only limited data such as those currently available with most LCTA data sets. Power analysis calculations also are relatively simple to conduct and are quite easily interpreted.

Objective

The first objective of this report is to describe and demonstrate relatively simple techniques that can be used by installation personnel to evaluate the ability of the LCTA monitoring protocols to detect changes in installation natural resources. The second objective is to apply these techniques to commonly used data summaries from a range of installations to quantify the ability of the LCTA monitoring protocols to detect changes in resources.

Approach

A literature survey was conducted to identify data analysis techniques commonly used for summarizing and interpreting LCTA data. A literature survey also was conducted to identify techniques that might be useful for assessing the ability of LCTA monitoring protocols to detect changes in installation resources. Information obtained from the literature surveys was then used to analyze a sample LCTA database from Fort Hood. The analysis of the data quantified the ability of the protocols to detect change for a range of data summaries. This analysis also quantified the impact on the power of LCTA data protocols of changing various parameters of the power analysis equations. Information from these analyses is intended to help installation, Major Command (MACOM), and Headquarters Department of the Army (HQDA) personnel understand the relative power of the

LCTA protocols for various levels of data summarization and understand the factors that affect the power of the protocols.

After detailed analysis of the Fort Hood LCTA data set, six Army installation data sets representing several diverse ecoregions were analyzed. These installations are representative of three contrasting biomes:

- grasslands (Fort Hood, Texas, and Fort Riley, Kansas)
- deserts (Fort Bliss, New Mexico, and Yakima Training Center, Washington)
- forestlands (Fort Drum, New York, and Fort Stewart, Georgia).

Analysis of data from these installations contrasted differences in the power of the LCTA monitoring protocols to detect trends in a range of data variables across diverse ecoregions.

The effects of poststratification on power were examined by stratifying installation LCTA data sets. Analyses assessed the impact of changes in sample size and variance associated with subsets of the installation data set on the power of the LCTA protocols to detect changes in resources. The consequences of stratification are relevant to installation personnel who frequently are interested only in trends in specific vegetation types or management units.

Also, the powers associated with subsets of variables that are commonly used in data summaries and modeling efforts were examined for a large number of installations. These results contrast the powers associated with LCTA sampling protocols for installations of varying size, sampling intensity, and mission importance. Results from this section will assist MACOM and HQDA personnel in evaluating the comparability of data summaries between installations.

Scope

In this report, the power of the LCTA protocols to detect changes in installation resources was assessed for only one type of statistical test. The almost limitless types of tests that can be conducted with LCTA data prevents an exhaustive assessment of the power associated with each type of test. However, results of the limited analyses conducted in this study are generally representative of the ability of the protocols to detect changes in resources for the range of tests applicable, and thus are useful to objectively assess the monitoring protocols.

The assessment of the ability of the LCTA monitoring protocols to detect changes in installation natural resources presented in this report only addresses the power of the protocols to detect change. This report does not specifically address issues such as the representativeness of the plot allocation scheme, sufficiency of the data for ground-truthing remotely sensed data, bias associated with the sampling methodology, or cost effectiveness of the current methodology.

Mode of Technology Transfer

Installation LCTA coordinators can incorporate these data summary methods and procedures into LCTA annual installation reports and other reporting mechanisms. Public domain software is currently available to assist installation personnel in data analysis.

2 Power Analysis

A tool commonly used in the statistical analysis of data is the test of a hypothesis (a test of significance) (Snedecor and Cochran 1980). The hypothesis under test is usually referred to as the null hypothesis (Ho) and is tested against the alternative hypothesis (Ha). For each hypothesis, the data is examined to see if the sample results support the hypothesis. The null hypothesis for many monitoring programs is that no change has occurred in the monitored resource. The alternative hypothesis is that a change has occurred.

Two types of errors are associated with any statistical test (Table 1). Type-I error (α) is the probability of rejecting the null hypothesis when the null hypothesis is true. Type-II error (β) is the probability of failing to reject the null hypothesis when the null hypothesis is false. If a resource manager interprets the output of a monitoring system as indicating that a biologically important change has occurred, some action will be taken. If a real change has occurred, the correct decision was made. If no change really has occurred, the manager is probably reacting to inherent variability in the process monitored; a false change (or Type-I) error would have been made and the manager would have taken actions that were not required. If a manager interprets the output of a monitoring system as indicating that no change has taken place, no action will be indicated. If, in reality, no change has taken place, this action would be the correct decision. However, if there really were a change that the monitoring system missed, a missed-change (or Type-II) error would have been made. Missed-change errors mean that a change, usually detrimental, was missed and that remedial actions will be delayed until a time when they may be more expensive or less effective.

Statistical power (1-β) is the probability that a particular test will reject the null hypothesis at a particular level (α) when the null hypothesis is false (Gill 1978). For monitoring programs, this is the probability that a change will be detected when a change has really occurred. A common misunderstanding of statistics often leads resource managers to interpret a failure to reject the null hypothesis

Table 1. Statistical decision and error probability table.

Truth	Statistical Decision	
	Reject Ho	**Fail to reject Ho**
Ho True	Type-I error (α)	No error (1-α)
Ho False	No error, Power (1-β)	Type-II error (β)

to mean that the null hypothesis is true. Whether the null hypothesis can be considered true depends on the power of the test (Cohen 1977). If a monitoring program has high power and a change in a resource has not been detected, a manager can conclude that no change has occurred in the resource. If the monitoring program has low power and a change has not been detected, the manager cannot conclude that a change has or has not occurred.

Failure to employ power analysis may result in the development and continuation of monitoring programs that are incapable of meeting monitoring objectives or the misinterpretation of results from existing monitoring programs. As a result, the literature is filled with papers arguing for increased use of power analysis in both the design and analysis stages of monitoring programs (Toft and Shea 1983; Rotenberry and Wiens 1985; Hayes 1987; Peterman 1990a; Peterman 1990b). Hayes (1987) reviewed the toxicology literature and found high power in only 19 of the 668 reports that failed to reject the null hypothesis. In many cases conclusions were made as if the null hypothesis was proven to be true. However, only in those studies with high power should the null hypothesis have been accepted as true. In the studies with low power, the results should have been interpreted as inconclusive. Numerous surveys of the power associated with studies reported in specific journals and representing many topic areas have shown similar results (Cohen 1977; Reed and Blaustein 1995; Forbes 1990).

Types of Power Analysis

Power analysis can be used a priori or a posteriori (Peterman 1990a). A priori power analysis is used in the design stage to determine the appropriate sample size required to yield a specified power (Peterman 1990b; Rotenberry and Wiens 1985; Toft and Shea 1983). A posteriori power analysis is used after data has been collected to determine the minimum detectable effect size for an existing survey (Rotenberry and Wiens 1985). The two approaches differ only in the data required and the parameters solved for in the equation.

The a priori use of power analysis is an important consideration when implementing a new LCTA program at an installation. Although the best sample size is the largest sample size, the rate of increase in precision and power decreases with increasing sample size (Green 1979). The question of concern with limited funds and manpower is not what is the best sample size but rather how many samples are required to meet management objectives. The original sample allocation protocol used in LCTA was based on the population size (land area) rather than the population variance (Diersing et al. 1992). As a result, recommended sampling intensity protocols may not be optimal because budgetary and logistic constraints are usually the primary factors dictating the magnitude of change that can be detected. Power analysis techniques using LCTA data from similar installations or preliminary surveys could be used to estimate desired sampling intensity based on ecological considerations.

The a posteriori use of power analysis is an important consideration for existing LCTA programs. The use of power analysis allows installation natural resource managers to determine minimum detectable effect sizes. Only by knowing the minimum detectable effect size for important variables can installation managers determine if the monitoring program is fulfilling management objectives. The a posteriori use of power analysis is emphasized in this report because a large number of installations have had LCTA programs for several years. Emphasis at these installations has shifted from the monitoring design and data collection phase to the data analysis and interpretation phase.

Biological Significance and Minimum Detectable Effect Size

Statistical significance is a statement about the magnitude of a variable without regard to the importance of the value. Biological or ecological significance is a statement about the magnitude of a value of a variable based on management considerations. Biological significance is related to statistical significance by considering the stability, power, and robustness of the survey methods employed in the monitoring program. Biological significance is more important than statistical significance when drawing a conclusion from sample data (Yoccoz 1991).

Effect size in power analysis is the degree of change one wants to detect by the test. The choice of effect size should be based on an understanding of the biology of the system and the economic and implementation constraints associated with the survey. Minimum detectable effect size is the smallest effect size that can be detected for a given sampling intensity and specified error levels. Determining the minimum detectable effect size helps ensure that statistical significance more closely corresponds to biological significance. If the minimum detectable effect size of a survey is larger than the effect size that would be considered biologically significant, the study design is considered to be weak (Cohen 1977). In weak study designs, small but biologically significant changes in the resource may not be detected. If the minimum detectable effect size of a survey is smaller than the effect size that would be considered biologically significant, the study design is considered to be strong. In strong study designs, biologically significant changes in the resource should be detected. Without specifying the minimum detectable effect size associated with a test, land managers are not provided the information necessary to judge the strength of the evidence provided (Peterman 1990b).

Effect size can be reported as absolute or relative effect size. Absolute effect size is the absolute change that can be detected regardless of the abundance of the variable being measured. The ability to detect an absolute change of 10 in the population implies that the protocols will detect a change of 10 when the mean is 10 and a change of 10 when the mean is 20. Relative effect size implies that the effect size will depend on the mean value of the variable being monitored. The ability to detect a 25 percent change in the population implies that the protocols will detect a change of 2.5 when the mean is 10 or a change of 5 when the mean is 20. The choice of reporting format is important and depends on the abundance of the variable being reported. Smith et al. (1995) reported that, for a given species of bird, greater than 200 plots were required to detect an absolute change of 0.25 birds and less than 50 plots were required to detect a relative change in population of 25 percent. Smith et al. (1995) also reported that, for a different species of bird, less than 50 plots were required to detect an absolute change of 0.25 birds and more than 200 plots were required to detect a relative change in population of 25 percent. The main difference between the two species of birds was the relative abundance of each species.

Both relative and absolute minimum detectable effect sizes are provided in this report. Specifying a meaningful change in population size is often difficult. Individuals may be better able to specify meaningful change in absolute or relative values. Depending on the magnitude and range of values for the variable of interest, a particular type of reporting may be more meaningful. Relative minimum detectable effect frequently is more easily interpreted and is the more common format reported in the literature.

Statistical Tests and Power Analysis

The determination of statistical significance and the estimation of the probability of error in the statistical conclusion are made within the framework of a particular statistical test. As such, the statistical test is one factor that determines the statistical power (Lipsey 1990). Numerous statistical tests are applicable to LCTA data trend analysis. Power equations for many of these tests are available. Population change over time and associated power can be estimated with two sample tests and paired tests using individual years (Cohen 1977). The same tests using the means of blocks of years before and after an event also can be used to make the tests less sensitive to random annual environmental variation (Cohen 1977). Gerrodette

(1987, 1991) provides power equations for regression tests for linear and exponential change. Green (1989) provides power equations for multivariate tests. Bernstein and Zalinski (1983) provide power equations for monitoring programs that also employ control plots. Although a number of power analysis models are available for use, Kendall et al. (1992) concluded that power estimates using data from the first and last years (two sample data) is a reasonable and robust procedure and is a good indicator of power, even for other trend tests.

For purposes of this report, paired plot comparisons (t-test) between 2 years were selected to determine the power of LCTA sampling protocols. This type of test was selected because paired tests are appropriate for repeated measurements associated with permanent sample plots (Snedecor and Cochran 1980). This type of analysis requires only 2 years of data. As such, this type of analysis is applicable to the majority of installations currently implementing LCTA. This applicability is especially true for data summaries that are available from long-term survey data collected only every 3 to 5 years (Tazik et al. 1992; Price et al. 1995). A requirement of only 2 years of data also may encourage installation personnel to employ the techniques early in the implementation process, when the results are most useful. The power associated with paired plot comparisons is more easily calculated than other methods so installation personnel may be more likely to make use of the technique during data analysis. This general type of analysis is applicable to many questions of interest to installation personnel. Power estimates associated with these tests are reasonable and robust indicators of the power associated with other types of tests (Kendall et al. 1992).

The null and alternative hypotheses associated with paired plot comparisons are shown in equations 1 and 2 (Green 1989). The null hypothesis is that there is no change in the monitored resource. The alternative hypothesis is that a change has occurred in the monitored resource.

Equation 1. The null hypothesis.

$$H_o : \mu_1 = \mu_2$$

Equation 2. The alternative hypothesis.

$$H_a : \mu_1 \neq \mu_2$$

where
μ_1 = first year mean
μ_2 = second year mean.

The power equations for paired plot comparisons used in this report are shown in equations 3 and 4 (Green 1989). Equation 3 is used to calculate the number of plots required to detect a specified effect size with specified values of α and β and an estimated variable variance. This equation represents the a priori use of statistical power analysis techniques. Equation 4 is used to calculate the minimal detectable effect size for specified values of α, β, sample size, and estimated variable variance. Equation 4 represents the a posteriori use of statistical power analysis techniques.

Equation 3. Power equation to estimate sample size (*a priori*).

$$n = \frac{(t_\alpha + t_\beta)^2 s^2}{\Delta^2}$$

Equation 4. Power equation to estimate minimum detectable effect size (*a posteriori*).

$$\Delta = \sqrt{\frac{(t_\alpha + t_\beta)^2 s^2}{n}}$$

where
n = sample size
α = Type-I error level
β = Type-II error level
t_α = student t value associated with α
t_β = student t value associated with β
Δ = effect size
s^2 = variance of the differences between measurements.

Data Assumptions Associated With Power Analysis

Equations 3 and 4 are appropriate for completely randomized sampling designs. However, the LCTA plot allocation protocol used at most installations was a stratified random sampling design with strata representing the cross product of unsupervised satellite image classes and soil survey classes (Warren et al. 1990). Stratified random sampling is often used to ensure that the sample will be more representative of the whole population. Stratified random sampling also is used to increase the precision of estimates of population characteristics (Snedecor and Cochran 1980). The original intent of stratification in the LCTA plot allocation protocol was to obtain a more uniform and representative sample of plots for the installation. A stratified random sample was used in the plot allocation, but too few observations exist in each strata to adequately estimate the variance for those strata. Because the stratification used in LCTA plot allocation was a proportional allocation based on the size of the strata, not using the strata does not bias the data summaries. Additionally, most summaries conducted by installation personnel analyze the data as a completely randomized sampling design. As a consequence, the sampling design was treated as if it were a completely randomized design when selecting the appropriate power analysis equations and estimating minimum detectable effect sizes.

Paired t-tests and the associated power equations assume that the variable of interest is normally distributed. Deviations from normality can affect the estimated power of the test. However, it has frequently been reported that violations of the normality assumption should be of little concern for t-tests (Glass et al. 1972; Cochran 1947; Eisenhart 1947). Cochran (1947) reports that the limits of error due to non-normal distribution for a two-tailed t-test at a 5 percent significance level are probably between 4 and 7 percent. Limits at a 1 percent significance level are between 0.5 and 2 percent. Scheffe (1959) indicated that kurtosis and skewness are the most important indicators of non-normality. Skewness measures the symmetry of a distribution. Skewed populations have little effect on the calculated power of two-tailed t-tests (Glass et al. 1972). Actual power deviates from nominal power by only a few percentages. However, skewed populations can seriously affect the power of directional (one-tailed) t-tests (Cochran 1947). Kurtosis is a term used to describe the peakedness of a distribution. Kurtosis has little effect on either one or two-tailed t-tests (Glass et al. 1972). Actual power is less than nominal power when populations are platykurtic (a kurtose distribution that is flatter than the normal distribution). Actual power exceeds nominal power when populations are leptokurtic (a kurtose distribution that is more peaked than a normal distribution). As a rule, non-normally distributed data result in slightly more significant results.

LCTA data are not always normally distributed. When analyzing non-normally distributed data, the data is often transformed to meet the assumptions of normality (Snedecor and Cochran 1980). However, data summaries in this report were not transformed for several reasons. LCTA data frequently is not transformed when analyzed. The tests used in this report are relatively insensitive to deviations from normality. Data is commonly not transformed in power analyses (Cohen 1977). Biologically significant minimum detectable effect sizes are more important than statistically significant minimum detectable effect sizes. Determining a biologically significant effect size of a variable is often difficult. Determining the biologically significant effect size of a transformed variable is even more difficult.

3 Factors Affecting Power—Fort Hood, Texas, an Installation Case Study

The power of any monitoring design is affected by several factors. Type-I error, sample size, effect size for the variable monitored, variance of the variable monitored, type of analysis conducted (statistical model), and type of test conducted (one-tailed vs. two-tailed) all affect the power of a test. The consequences of changes in any of these factors is important when designing a survey or analyzing data from an existing survey. The power of a monitoring program increases as the acceptable rate of Type-I error becomes larger; sample precision increases through increased sample size or implementation of quality control programs, and the minimum detectable effect size that is acceptable is increased. When the power of monitoring protocols is insufficient for management objectives, installation personnel can accept alternative values for the power equation's factors. In this manner, installation personnel can determine if increasing the minimum detectable effect size will enhance the power of the design to a greater extent than increasing the Type-I error probability that is acceptable. Methodology changes or quality control programs that increase precision of variable estimates also can be contrasted to changes in acceptable error rates or minimum detectable effect sizes.

Of the variables affecting the power of the survey protocols, only changes in sample size directly affect the cost of attaining greater power. Changes in the other factors only indirectly affect costs through incorrect inferences drawn from the data that result from less restrictive error rates and effect sizes.

This section quantifies the effect of changes in the power equation factors on the power of LCTA monitoring protocols. Data from the Fort Hood, Texas, LCTA program were selected to examine in detail the factors affecting power of tests associated with LCTA data analysis efforts. Fort Hood data were selected for use because this data set also was used in a LCTA data summary case study (Price et al. 1995). The data used in this section are the same data used in the study by Price et al. (1995) and are discussed in greater detail in that report. Data sets for 1989 and 1992 were used for all analyses. These years represent the initial LCTA survey (1989) and the first long-term survey (1992). Those years were selected because many of the variables summarized were only available from initial/long-term surveys. Although some of the variables were available from short-term surveys, a decision was made to use a common data set for all variables. Only plots that were monitored in each year and for all variables were used in the analysis. Relative minimum detectable effect size is always presented as a percentage of the first year's data (1989).

Fort Hood, Texas, Site Description

The Fort Hood master plan report (Nakata Planning Group 1987) contains detailed information on the Fort Hood environment. Fort Hood occupies an 87,890 ha area in Central Texas in Bell and Coryell Counties. Elevation at Fort Hood ranges from 180 m to 375 m above sea level, with 90 percent below 260 m. Most slopes are in the 2 to 5 percent range, with slopes in excess of 45 percent occurring as bluffs along the floodplain and as the side slopes of the mesa-hills. Soil cover is generally shallow to moderately deep and clayey, underlain by limestone bedrock. Fort Hood lies in the Cross Timbers and Prairies vegetation area. This area is normally composed of oak woodlands with grass undergrowth. Traditionally, the predominant woody vegetation consisted of ashe juniper (*Juniperus ashei*), live oak (*Quercus fusiformis*), and Texas oak (*Quercus texana*). Under climax conditions, the predominant grasses consisted of little bluestem (*Schizachyrium scoparium*) and Indian grass (*Sorghastrum nutans*).

The primary mission of Fort Hood is training, housing, and support of the III Corps and its two divisions (1st Calvary Division and 2nd Armored Division). Support also is provided to other assigned and tenant organizations, the U.S. Army Reserve, the National Guard, the Reserve Officer Training Corps, and the reservists from other services. Live fire and impact areas occupy about 22,700 ha, 8,700 ha of which are multipurpose maneuver, live-fire areas. The range areas serve as familiarization and qualification firing ranges for all individual weapons, crew-served weapons, and the major weapons systems of active units assigned to or attached to the III Corps and Fort Hood. Maneuver areas comprise 52,400 ha, not including the multipurpose, live-fire area. Maneuver areas are used for armored and mechanized infantry forces in the conduct of task force and battalion-level operations, and for company and platoon level dismounted training as well as engineer, amphibious, combat support, and combat services support training.

Minimum Detectable Effect Sizes for Selected α and β Error Rates

Careful thought should be given to the consequences of both Type-I and Type-II statistical errors and the appropriate rates of errors that are accepted. A Type-I error means that a management practice such as site rehabilitation may be implemented where it is not necessary. A Type-II error means that a necessary management practice may not be implemented because the problem is not detected. The more stringent the standard set for Type-I error, the more likely a Type-II error will occur for a given sampling intensity.

Determination of appropriate α and β levels should be based on the relative cost of committing Type-I and Type-II errors and should be based on criteria external to the data (Cohen 1977; Toft and Shea 1983; Rotenberry and Wiens 1985; Green 1989). In some circumstances the ecological/management consequences of wrongly concluded change in a variable when none has occurred (Type-I error) may be equivalent to the consequences of failing to detect change (Type-II error). Under those conditions, the errors should be treated equally in the analysis of data. In natural resources management, Type-II errors often are considered more costly than Type-I errors (Hayes 1987; Peterman 1990a; Thompson and Schwalbach 1995). Setting β lower than α implies that the cost of Type-II errors are higher than the cost of Type-I errors (Toft and Shea 1983). The relative costs will determine the acceptable error levels for each type of error and are likely to be installation and management-objective specific. For example, the cost of an extensive rehabilitation program may outweigh the costs of increased monitoring effort required to detect a problem early on when rehabilitation may be less expensive. The cost of not modifying training levels and rotating training areas when needed may or may not exceed the cost of modifying training prematurely and implementing other rehabilitation programs.

Table 2 shows the effect of changing α and β levels on the minimum detectable effect size for disturbance, bare ground, and canopy cover. Increasing α or β decreases the minimum detectable effect size. Equivalent changes in minimum detectable effect sizes occur for similar changes in either α or β. Peterman (1990a) suggested that power be at least 0.8, or more conservatively 0.9, for environmental monitoring programs. Thompson and Schwalbach (1995) recommend accepting higher Type-I error rates of 0.1 to increase statistical power to greater than 0.8 for bird monitoring programs. Relatively conservative Type-I and Type-II error rates (α=β=0.10) were used in the rest of this report.

Minimum Detectable Effect Sizes for One-tailed and Two-tailed Tests

The use of one-tailed (directional) tests can increase the efficiency of a study by reducing the required sample size or decreasing the minimum detectable effect size for an existing study. One-tailed tests are used only when there is reason to expect results in one direction (Snedecor and Cochran 1980; Sokal and Rohlf 1981). When

Table 2. Effect of changing Type-I and Type-II error rates on the minimum detectable effect size (MDES) for disturbance, bare ground, and canopy cover estimates for Fort Hood, Texas.

Variable	Type-I Error Rate (α)	Power (1-β)					
		Relative MDES[1]			Absolute MDES[2]		
		0.95	0.90	0.80	0.95	0.90	0.80
Disturbance	0.05	27.3	23.0	20.8	8.0	6.8	6.1
	0.10	24.2	19.9	17.6	7.1	5.9	5.2
	0.20	23.1	18.6	16.5	6.8	5.5	4.9
Bare ground	0.05	18.0	15.1	13.7	6.1	5.1	4.7
	0.10	16.0	13.1	11.6	5.4	4.5	4.0
	0.20	15.2	12.3	10.8	5.2	4.2	3.7
Canopy cover	0.05	7.4	6.2	5.6	6.0	5.0	4.5
	0.10	6.5	5.4	4.8	5.2	4.4	3.9
	0.20	6.2	5.0	4.4	5.0	4.0	3.5

[1] Relative minimum detectable effect size as a percentage of the first year's (1989) mean.
[2] All minimum detectable effect sizes are for paired two-tailed t-tests.

analyzing LCTA data, there are many instances in which results in only one direction may be expected and are of concern. Military impacts frequently result in decreased vegetation cover, increased soil exposure, and increases in introduced species (Severinghaus et al. 1979, 1980; Shaw and Diersing 1990; Thurow et al. 1993; Trumbull et al. 1994; Wilson 1988). One-tailed tests may be justified when testing for the effects of increased training.

Minimum detectable effect sizes for one-tailed and two-tailed tests are shown in Table 3 for disturbance, bare ground, and canopy cover estimates. One-tailed tests

Table 3. Effect of test type on minimum detectable effect size (MDES) for disturbance, bare ground, and canopy cover estimates for Fort Hood, Texas.

Variable	Type I and II Error Rates	Relative MDES[1]		Absolute MDES[2]	
		Two-tailed	One-tailed	Two-tailed	One-tailed
Disturbance	0.05	27.3	25.5	8.0	7.5
	0.10	19.9	17.6	5.9	5.2
Bare ground	0.05	18.0	16.8	6.1	5.7
	0.10	13.1	11.6	4.5	4.0
Canopy cover	0.05	7.4	6.9	6.0	5.6
	0.10	5.4	4.8	4.4	3.9

[1] Relative minimum detectable effect size as a percentage of the first year's (1989) mean.
[2] All minimum detectable effect sizes are for paired two-tailed t-tests.

had smaller minimum detectable effect sizes than two-tailed tests. These results are similar to other published results for monitoring programs. Thompson and Schwalbach (1995) found sample size requirements to detect a 20 percent change in population increased 22 percent for a two-tailed test as compared to a one-tailed test. D.K. Niven (unpublished data, 1994) reported sample size requirements to detect a 20 percent change in population increased approximately 30 percent for a two-tailed test as compared to a one-tailed test.

For all other tests in this report, two-tailed tests are used because they are less sensitive to violations of the assumption of normality. Two-tailed tests are probably more accurate for interpreting data that are of most interest to most installation personnel. Minimum detectable effect sizes for two-tailed tests also can be considered as conservative estimates of minimum effect sizes for one-tailed tests.

Minimum Detectable Effect Sizes for Selected LCTA Data Variables

In most surveys, a leading variable usually is identified to estimate the sample size required for the survey (Reich and Arvanitis, 1992). As a consequence, other variables of interest are either undersampled or oversampled based on the relative abundance and distribution of each variable. Thus, one would expect a wide range of minimum detectable effect sizes for the range of variables that can be computed from LCTA data.

Table 4 shows the minimum detectable effect sizes for a range of variables derived from Fort Hood LCTA data. These summaries represent only a portion of the possible data summaries, but they include a wide range of summaries commonly used with LCTA data. Minimum detectable effect size for each summary is reported in relative and absolute terms. Relative minimum detectable effect sizes varied considerably among the vegetation variables summarized. Relative minimum detectable effect sizes ranged from about 5 percent for canopy cover to over 200 percent for introduced cover. Even individual species summaries had relative minimum detectable effect sizes that ranged from 37 percent to over 200 percent. In general, presence/absence measures had smaller relative minimum detectable effect sizes than equivalent total intercept measures for line intercept transect data. Less detailed summaries (canopy cover, annual cover) had smaller relative minimum detectable effect sizes than more detailed summaries (species level summaries). Generally, trends in absolute minimum detectable effect sizes were similar to trends in relative minimum detectable effect sizes.

Table 4. Comparison of minimum detectable effect size for selected variables for Fort Hood, Texas.

Transect Type[1]	Variable		Mean[3]	Minimum Detectable Effect Size[4]	
	Type[2]	Measure		Relative	Absolute
Line	PA	Disturbance	29.5	19.9	5.9
	PA	Bare ground	34.1	13.1	4.5
	PA	Canopy cover	80.6	5.4	4.4
	PA	Cover >4 m	13.1	12.3	1.6
	PA	Annual cover	9.7	77.0	7.5
	PA	Perennial cover	76.9	9.9	7.6
	PA	Introduced cover	6.2	130.6	8.1
	PA	Native cover	77.7	10.6	8.2
	PA	Grass, annual	4.0	31.1	1.3
	PA	Grass, perennial	50.8	8.0	4.1
	PA	Forb, annual	6.0	37.1	2.2
	PA	Forb, perennial	9.6	21.1	2.0
	PA	Shrub, broadleaf	9.9	12.6	1.2
	PA	Tree, broadleaf	9.7	16.7	1.6
	PA	Tree, coniferous	14.0	8.5	1.2
	PA	Individual species[5]	0.9-14.6	29.4-238.6	2.2-5.5
	Total	Total cover	246.7	8.4	20.7
	Total	Annual cover	13.7	193.1	26.5
	Total	Perennial cover	233.0	14.1	32.9
	Total	Introduced cover	12.2	225.1	27.5
	Total	Native cover	237.1	14.1	33.4
	Total	Grass, annual	5.6	33.4	1.9
	Total	Grass, perennial	88.3	11.3	10.0
	Total	Forb, annual	8.0	48.2	3.9
	Total	Forb, perennial	12.0	28.0	3.4
	Total	Shrub, broadleaf	31.6	16.6	5.2
	Total	Tree, broadleaf	33.8	21.0	7.1
	Total	Tree, coniferous	63.0	17.8	11.2
	Total	Individual species	1.1-63.0	37.0-500.2	5.8-23.9
Belt	Total	Total vegetation	96.0	17.8	17.1
	Total	Total shrubs	33.3	46.7	15.5
	Total	Total trees	62.8	32.4	20.3
	Total	Total dead	3.0	44.7	1.3

Transect Type[1]	Variable		Mean[3]	Minimum Detectable Effect Size[4]	
	Type[2]	Measure		Relative	Absolute
	Total	Live < 1 m	50.7	24.0	12.2
	Total	Live 1-2 m	21.9	21.2	4.7
	Total	Live 2-3 m	8.4	26.1	2.2
	Total	Live 3-4 m	5.0	28.7	1.5
	Total	Live >4 m	9.9	23.9	2.4
	Total	Individual species, all heights	0.9-24.0	45.5-434.1	3.8-10.9

1 Line indicates data from the 100 m line transect. Belt indicates data from the 600 m^2 belt transect.
2 PA is the percentage of transect points within a plot with observed occurrences. Values range from 0 to 100. Total is the total number of points within a plot with observed occurrence for line observations; these values range from 0 to 3200. The values for belt observation are the number of individuals per plot.
3 Average value of the first year's (1989) measurement.
4 All minimum detectable effect sizes are for two-tailed paired t-tests. Relative minimum detectable effect size is presented as a percentage change in the first year's (1989) measurement. Type-I error rate (α) set to 0.1. Type-II error rate (β) set to 0.1 (power=0.9).
5 Individual species is the range of values for the 20 most common species based on total intercepts on the line transect from the first year's (1989) data for all core plots.

Considerable literature exists that documents changes in natural resources in terms of impacts of treatments, annual and seasonal variation, and historic trends, but few publications specifically report what constitutes a biologically significant change. Kendall et al. (1992) suggested that a detectable population change of 20 percent when monitoring grizzly bears in Glacier National Park represented a satisfactory, noncatastrophic change for bear populations. A 20 percent change among avian population means were used to determine required sample sizes by Thompson and Schwalbach (1995), Hanowski et al. (1990), and Hanowski and Niemi (1995). Smith et al. (1995) considered a population change of 25 percent as biologically significant and representative of an achievable goal for land managers. For most LCTA variables, assessments based on individual expertise will be required to define biologically significant change and are likely to be installation specific.

Two alternative approaches that do not modify current sampling protocols are available when confronted with minimum detectable effect size concerns for less common species and other finer resolution variables. The first approach involves selecting a subset of the LCTA data that contains plots with a higher probability of containing the species or variable. Data subsets may be based on vegetation types, soils types, topography, or other variables. This approach has been recommended for bird surveys (Thompson and Schwalbach 1995; Hayden and Tazik 1993). A second approach involves monitoring a coarser resolution variable that is an indicator of the finer resolution variable. This approach frequently is used in avian monitoring when guilds are used instead of individual species (Thompson and Schwalbach 1995;

Call 1981; Croonquist and Brooks 1991; Landres 1983; Severinghaus 1981; Short 1983), as has been done with LCTA bird surveys (Price et al. 1995).

4 Comparison of Minimum Detectable Effect Sizes for Installations From Diverse Ecoregions

Data from six Army installations representing several diverse ecoregions were analyzed to contrast the minimum detectable effect size associated with a range of variables for each installation. The installations represent three diverse biomes and six distinct ecotypes (Table 5). Data used in the analyses consisted of the initial survey data and first survey that had both long-term line transect and long-term belt transect data. Short-term survey data were not used because species level data were not available for those surveys, and a decision was made to use a common data set for all variables within an installation. Only plots measured in both years were used, and only core plot data was used because the summaries represented installation-wide summaries. Only data from plots that had all variables measured were included in the analyses to maintain a common data set for all variables within an installation. Even with these restrictions, only a few plots were excluded from any installation. Data summaries selected for use are based on LCTA summaries described by Price et al. (1995).

Table 6 shows minimum detectable effect sizes for a range of variables for the six installations. Trends in minimum detectable effect sizes among installations were

Table 5. Description of installations used in comparisons of minimum detectable effect sizes of selected variables among diverse ecoregions.

Installation	Biome	Ecoregion[1]
Fort Bliss, New Mexico	Desert	Southwest Desert
Yakima Training Center, Washington	Desert	Intermountain Northwest Desert
Fort Hood, Texas	Grassland	Southern Prairie/Cross Timbers
Fort Riley, Kansas	Grassland	Central Prairie
Fort Stewart, Georgia	Forest	Southeast Mixed Forest
Fort Drum, New York	Forest	Northeast Deciduous Forest

[1] Ecoregions based on Bailey et al. (1994)

generally similar in that presence/absence measures had smaller minimum detectable effect sizes than equivalent total intercept measures for line intercept transect data. Also, less detailed summaries (canopy cover, annual cover) had smaller minimum detectable effect sizes than more detailed summaries (species level summaries) for all installations. Differences between installations were apparent for some data summaries. Differences generally were attributed to differences in the amounts and types of vegetation present. Minimum detectable effect sizes for canopy cover above 4 m and the amount of forbs varied considerably between installations. These differences generally reflected the relative abundance and distribution of the variable at each installations. At Yakima Training Center, for example, canopy cover above 4 m was essentially nonexistent, but at Fort Drum a large proportion of plots had considerable cover above 4 m.

Table 6. Relative minimum detectable effect sizes for selected variables at six Army installations representing diverse ecoregions.

Transect Type[1]	Variable		Relative Minimum Detectable Effect Size[3]					
	Type[2]	Measure	Hood	Riley	Yakima	Bliss	Drum	Stewart
Line	PA	Disturbance	19.9	24.9	32.1	34.0	46.1	48.9
	PA	Bare ground	13.1	24.0	8.7	7.3	17.4	23.9
	PA	Canopy cover	5.4	4.5	5.4	6.6	2.7	2.1
	PA	Cover >4 m	12.3	74.7	0.0	17.5	2.8	2.8
	PA	Annual cover	77.0	314.4	49.0	84.9	1408.7	1409.0
	PA	Perennial cover	9.9	18.3	10.7	10.1	12.1	10.3
	PA	Introduced cover	130.6	99.8	51.6	516.4	52.2	4359.0
	PA	Native cover	10.6	19.2	13.0	9.8	13.5	10.5
	PA	Grass, annual	31.1	79.3	23.9	51.2	932.8	1264.2
	PA	Grass, perennial	8.0	8.5	6.1	10.2	11.1	15.6
	PA	Forb, annual	37.1	146.7	76.9	36.3	75.7	154.4
	PA	Forb, perennial	21.1	38.0	24.0	30.7	7.7	37.0
	PA	Shrub, broadleaf	12.6	92.8	13.9	9.1	7.8	8.1
	PA	Tree, broadleaf	16.7	39.0	—[5]	9.2	2.4	3.5
	PA	Tree, coniferous	8.5	135.4	—	20.1	5.0	12.8
	PA	Individual species[4]	29.4-238.6	18.3-1-008.9	11.3-580.1	40.0-250.2	37.2-156.2	29.7-107.8
	Total	Total cover	8.4	18.1	5.2	8.0	4.9	4.6
	Total	Annual cover	193.1	1008.9	70.9	109.2	4397.5	3164.7
	Total	Perennial cover	14.1	33.7	13.2	10.7	13.2	11.8

Transect Type[1]	Variable		Relative Minimum Detectable Effect Size[3]					
	Type[2]	Measure	Hood	Riley	Yakima	Bliss	Drum	Stewart
	Total	Introduced cover	225.1	295.1	73.3	563.5	104.6	8234.7
	Total	Native cover	14.1	33.9	13.0	10.5	15.7	12.0
	Total	Grass, annual	33.4	127.0	28.5	55.6	757.4	1656.8
	Total	Grass, perennial	11.3	24.2	7.8	12.4	14.6	18.6
	Total	Forb, annual	48.2	213.8	95.6	40.6	90.6	147.8
	Total	Forb, perennial	28.0	48.6	27.7	35.1	10.7	42.2
	Total	Shrub, broadleaf	16.6	128.5	20.1	9.9	12.2	11.1
	Total	Tree, broadleaf	21.0	43.2	—	14.4	4.8	5.9
	Total	Tree, coniferous	17.8	75.2	—	15.6	9.8	13.5
	Total	Individual species	37.0-500.2	50.1-424.5	21.4-855.7	29.4-241.4	41.3-170.8	39.3-125.8
Belt	Total	Total vegetation	17.8	39.0	19.3	12.3	14.9	16.3
	Total	Total shrubs	46.7	61.9	24.1	29.0	49.0	26.2
	Total	Total trees	32.4	282.3	—	244.2	25.8	31.0
	Total	Total dead	44.7	57.4	4.9	31.8	23.3	155.5
	Total	Live < 1 m	24.0	46.4	19.6	12.8	98.2	35.1
	Total	Live 1-2m	21.2	92.4	94.3	17.9	20.1	27.7
	Total	Live 2-3 m	26.1	103.9	125.2	74.2	18.3	23.2
	Total	Live 3-4 m	28.7	111.6	171.9	75.4	20.8	25.4
	Total	Live >4 m	23.9	77.1	158.8	64.7	21.5	7.1
	Total	Individual species, all heights	45.5-434.1	76.6-17208.3	41.4-13958.9	17.6-909.7	59.8-237.5	45.7-306.5

[1] Line indicates data from the 100 m line transect. Belt indicates data from the 600 m^2 belt transect.
[2] PA is the percentage of transect points within a plot with observed occurrence. Values range from 0 to 100. Total is the total number of points within a plot with observed occurrence for line observations, these values range from 0 to 3200. The values for belt observation are the number of individuals per plot.
[3] All minimum detectable effect sizes are for two-tailed paired t-tests. Relative minimum detectable effect size is presented as a percentage change in the first year measurement. Type-I error rate (α) set to 0.1. Type-II error rate (β) set to 0.1 (power=0.9).
[4] Individual species is the range of values for the 20 most common species based on total intercepts on the line transect for the first year's (1989) data and only core plots.
[5] — Indicates the mean value was zero so relative minimum detectable effect sizes cannot be calculated.

5 Effect of Poststratification and Data Subsets on Minimum Detectable Effect Sizes

Poststratification is the practice of stratifying a sample after the data is collected (Snedecor and Cochran 1980). Strata usually consist of a subset of the data that are related and, as a group, are more homogenous than the complete sample. Examples of poststratification of LCTA data include grouping plots by vegetation types, land use, or soil type. Installation personnel may want to poststratify LCTA data sets for several reasons. The first reason to poststratify LCTA data sets is to increase the precision of installation level statistics by pooling strata variances (Snedecor and Cochran 1980; Thompson and Schwalbach 1995). The second reason to poststratify LCTA data sets is to compute statistics for subsets of the complete data set (Price et al. 1995). Statistics for subsets of the data allow monitoring of trends for portions of the installation. Calculating statistics on subsets of the data has been proposed as a means to increase the ability of monitoring programs to detect changes in resources (Thompson and Schwalbach 1995; Hayden and Tazik 1993). Post-stratification of LCTA data to compute statistics for subsets of the data will be examined here.

Poststratification can affect the power of LCTA monitoring protocols to detect changes in natural resources by affecting both the sample size and the sample variance. Decreases in sample size associated with subsets of the data may decrease the power to detect changes. However, a more homogenous subsample with reduced variance estimates may increase power. To investigate the consequences of post-stratification of LCTA data sets on the power of the protocols to detect changes in resources, two installation data sets (Fort Hood, Texas, and Fort Drum, New York) were stratified. Minimum detectable effect sizes for selected variables were then calculated for each strata.

In the first example of poststratification, core plots located in central, east, south, and west Fort Hood were grouped together by region and analyzed separately based on substantial differences in military training activities, general vegetation types, and topography as described in Price et al. (1995). The intent was to isolate patterns of general land use combined with general topography and vegetation type while maintaining sample sizes that were statistically sound. The intent was not to make comparisons among the different regions but to monitor trends within a region. East Fort Hood is dominated by oak-juniper woodlands on high, mesa-like hills with geologic cuts and slopes up to 45 percent. This region is used primarily for small unit exercises, bivouac, and foot soldier training. West and south Fort Hood is a savannah type dominated by midgrasses, little bluestem, tall dropseed, and Texas wintergrass with scattered motts of live oak on rolling topography; oak-juniper is on hills and steep slopes along the major drainages. The west and south regions are used primarily for tracked and wheeled maneuver exercises at the battalion level on west Fort Hood and at the smaller platoon level on south Fort Hood. Central Fort Hood has a mixture of the savannah type on rolling topography with oak-juniper woodlands on mesa tops and along steep slopes of drainages. Central Fort Hood contains a 22,700 ha live-fire and artillery impact area and an additional 8,700 ha multi-purpose maneuver live-fire range (Nataka Planning Group 1987).

Table 7 contrasts minimum detectable effect sizes for the installation and regional data sets. Minimum detectable effect sizes for all variables were greater for regional summaries than for installation summaries. Variances and sample sizes for each strata are presented in Table 8 for selected variables. Even for variables that showed decreased variance estimates for regional summaries, minimum detectable effect sizes were larger than for installation level summaries. Decreases in sample size more than offset any decreases in variance for regional summaries in this example.

Table 7. Relative minimum detectable effect sizes for selected variables for Fort Hood, Texas, management unit data subsets.

Transect Type[1]	Variable		Relative Minimum Detectable Effect Size[3]				
	Type[2]	Measure	Installation	Central	East	South	West
Line	PA	Disturbance	19.9	65.4	51.4	53.7	22.0
	PA	Bare ground	13.1	26.0	30.1	38.1	19.4
	PA	Canopy cover	5.4	10.3	10.9	10.6	9.1
	PA	Cover >4 m	12.3	17.5	14.3	53.6	38.8
	PA	Annual cover	77.0	258.0	131.2	266.8	93.7
	PA	Perennial cover	9.9	20.3	18.8	28.3	15.6
	PA	Introduced cover	130.6	519.6	179.6	664.7	174.9
	PA	Native cover	10.6	21.1	19.3	30.2	18.6
	PA	Grass, annual	31.1	86.5	39.5	162.2	58.5
	PA	Grass, perennial	8.0	14.8	21.7	15.2	11.6
	PA	Forb, annual	37.1	68.0	68.3	118.1	59.4
	PA	Forb, perennial	21.1	40.8	37.7	40.2	36.2

Transcect Type[1]	Variable		Relative Minimum Detectable Effect Size[3]				
	Type[2]	Measure	Installation	Central	East	South	West
	PA	Shrub, broadleaf	12.6	16.2	19.3	30.4	28.5
	PA	Tree, broadleaf	16.7	28.1	21.3	119.1	37.6
	PA	Tree, coniferous	8.5	11.8	8.2	24.7	45.8
	PA	Individual species[4]	29-238	41-207	47-232	78-722	37-222
	Total	Total cover	8.4	18.1	12.1	26.3	14.9
	Total	Annual cover	193.1	616.3	356.2	588.7	219.9
	Total	Perennial cover	14.1	27.4	23.1	36.7	25.8
	Total	Introduced cover	225.1	689.5	370.6	855.1	290.4
	Total	Native Cover	14.1	26.9	23.2	36.9	26.4
	Total	Grass, annual	33.4	93.8	36.9	157.6	70.9
	Total	Grass, perennial	11.3	22.7	28.6	26.3	15.5
	Total	Forb, annual	48.2	69.3	111.4	179.8	70.6
	Total	Forb, perennial	28.0	59.3	46.0	47.0	42.7
	Total	Shrub, broadleaf	16.6	22.9	25.1	44.7	35.0
	Total	Tree, broadleaf	21.0	23.6	28.8	160.4	40.3
	Total	Tree, coniferous	17.8	36.0	20.1	61.3	56.1
	Total	Individual species	37-500	51-421	47-444	93-1397	45-390
Belt	Total	Total vegetation	17.8	24.2	28.3	52.8	47.2
	Total	Total shrubs	46.7	69.0	96.4	104.6	69.0
	Total	Total trees	32.4	57.3	49.4	77.6	59.0
	Total	Total dead	44.7	73.4	63.5	186.2	116.0
	Total	Live < 1 m	24.0	41.5	38.0	57.5	54.8
	Total	Live 1-2 m	21.2	25.6	32.5	119.0	63.1
	Total	Live 2-3 m	26.1	23.1	37.7	75.3	99.4
	Total	Live 3-4 m	28.7	60.9	35.5	69.8	57.2
	Total	Live >4 m	23.9	31.0	36.4	49.6	64.8
	Total	Individual species, all heights	45-434	86-201	50-137	88-268	79-381

1 Line indicates data from the 100 m line transect. Belt indicates data from the 600 m^2 belt transect.
2 PA is the percentage of transect points within a plot with observed occurrences. Values range from 0 to 100. Total is the total number of points within a plot with observed occurrence for line observations, these values range from 0 to 3200. The values for belt observation are the number of individuals per plot.
3 All minimum detectable effect sizes are for two-tailed paired t-tests. Relative minimum detectable effect size is presented as a percentage change in the first year's (1989) measurement. Type-I error rate (α) set to 0.1. Type-II error rate (β) set to 0.1 (power=0.9).
4 Individual species is the range of values for the 20 most common species based on total intercepts on the line transect from the first year's (1989) data for all core plots.

Table 8. Variance (σ^2) and sample sizes (n) for Fort Hood, Texas, management unit data subsets.

Variable	Installation		Central		East		South		West	
	σ^2	n	σ^2	n	σ^2	n	σ^2	n	σ^2	n
Disturbance	714.3	163	562.3	47	814.1	44	622.6	16	716.6	56
Bare ground	413.1	163	546.8	47	279.1	44	430.8	16	404.4	56
Canopy cover	385.3	163	415.4	47	502.1	44	156.2	16	328.6	56

In a second example of poststratification, Fort Drum core plots representing distinct vegetation cover classes were grouped and analyzed separately. As with the Fort Hood example, the intent was to isolate patterns of general land and vegetation type while maintaining sample sizes that were statistically sound. Only core plots located in coniferous forest, deciduous forest, grassland, and shrubland cover classes were analyzed. Cover classes for each LCTA plot were obtained from a vegetation cover map provided by Fort Drum natural resources personnel (Costal Environmental Services 1993). The vegetation classification system used a modification of the New York Natural Heritage Program plant community classification system (Nature Conservancy 1982). Fort Drum is approximately 57 percent wooded, 8 percent shrubland, and 20 percent grassland. Coniferous and deciduous forests were characterized by greater than 60 percent coniferous or deciduous cover, respectively. Forestlands are used primarily for bivouacking and foot soldier training. Shrublands contain less than 25 percent tree cover, and grasslands contain less than 50 percent shrub cover. These cover types are used primarily for tracked and wheeled maneuver exercises.

Table 9 contrasts minimum detectable effect sizes for the installation and cover class data sets. Minimum detectable effect sizes for most variables were greater for cover class summaries than for installation summaries. Variances and sample sizes for each strata are presented in Table 10 for selected variables. As with the Fort Hood example, variables that showed decreased variance estimates for cover class summaries frequently had larger minimum detectable effect sizes than the installation summaries. Decreases in sample sizes, for the most part, more than offset any decreases in variance for cover class summaries in this example.

Table 9. Relative minimum detectable effect sizes for selected variables for Fort Drum, New York, vegetation cover class data subsets.

Transect Type[1]	Variable		Relative Minimum Detectable Effect Size[3]				
	Type[2]	Measure	Installation	Conifer Forest	Decidu-ous Forest	Grassland	Shrubland
Line	PA	Disturbance	46.1	89.5	127.8	53.4	258.8
	PA	Bare ground	17.4	92.1	53.5	22.4	100.0
	PA	Canopy cover	2.7	1.9	1.4	9.4	7.8
	PA	Cover >4 m	2.8	6.5	3.7	70.8	85.1
	PA	Annual cover	1408.7	—[4]	5756.4	1229.9	—
	PA	Perennial cover	12.1	42.1	22.4	23.8	51.3
	PA	Introduced cover	52.2	514.2	1134.5	22.5	113.1
	PA	Native cover	13.5	41.9	22.1	26.0	41.9
	PA	Grass, annual	932.8	—	—	925.2	—
	PA	Grass, perennial	11.1	18.0	15.4	14.2	39.4
	PA	Forb, annual	75.7	—	82.9	123.1	—
	PA	Forb, perennial	7.7	26.3	12.6	15.2	26.3
	PA	Shrub, broadleaf	7.8	38.6	14.7	24.9	24.0
	PA	Tree, broadleaf	2.4	8.1	2.3	33.9	36.9
	PA	Tree, coniferous	5.0	5.3	23.0	281.0	70.3
	Total	Total cover	4.9	10.5	6.8	14.0	39.4
	Total	Annual cover	4397.5	—	19499.8	2576.2	—
	Total	Perennial cover	13.2	41.9	24.6	25.5	55.8
	Total	Introduced cover	104.6	1091.0	3969.5	35.2	343.6
	Total	Native cover	15.7	43.0	24.4	39.8	59.5
	Total	Grass, annual	757.4	—	—	746.5	—
	Total	Grass, perennial	14.6	35.0	24.9	17.2	46.2
	Total	Forb, annual	90.6	—	79.0	140.6	—
	Total	Forb, perennial	10.7	22.8	16.1	20.6	37.1
	Total	Shrub, broadleaf	12.2	19.0	21.3	31.4	52.9
	Total	Tree, broadleaf	4.8	11.5	6.5	34.4	65.6
	Total	Tree, coniferous	9.8	16.3	30.5	281.0	151.3
Belt	Total	Total vegetation	14.9	46.3	16.7	70.9	94.0
	Total	Total shrubs	49.0	406.9	122.0	111.4	121.9
	Total	Total trees	25.8	68.6	34.1	165.0	242.0
	Total	Total dead	23.3	80.4	44.1	58.7	36.6

Transect Type[1]	Variable		Relative Minimum Detectable Effect Size[3]				
	Type[2]	Measure	Installation	Conifer Forest	Decidu-ous Forest	Grassland	Shrubland
	Total	Live < 1 m	98.2	144.1	38.8	279.5	159.9
	Total	Live 1-2 m	20.1	33.9	23.4	60.3	100.9
	Total	Live 2-3 m	18.3	36.3	25.8	99.6	174.6
	Total	Live 3-4 m	20.8	67.4	32.4	144.6	141.0
	Total	Live >4 m	21.5	71.0	28.8	208.5	152.8

1 Line indicates data from the 100 m line transect. Belt indicates data from the 600 m^2 belt transect.
2 PA is the percentage of transect points within a plot with observed occurrence. Values range from 0 to 100. Total is the total number of points within a plot with observed occurrences for line observations, these values range from 0 to 3200. The values for belt observation are the number of individuals per plot.
3 All minimum detectable effect sizes are for two-tailed paired t-tests. Relative minimum detectable effect size is presented as a percentage change in the first year's (1989) measurement. Type-I error rate (α) set to 0.1. Type-II error rate (β) set to 0.1 (power=0.9).
4 — Indicates the mean value was zero so relative minimum detectable effect sizes cannot be calculated.

Table 10. Variance (σ^2) and sample sizes (n) for Fort Drum, New York, vegetative cover class data subsets.

Variable	Installation		Conifer Forest		Deciduous Forest		Grassland		Shrubland	
	σ^2	n	σ^2	n	σ^2	n	σ^2	n	σ^2	n
Disturbance	502.9	143	1.9	12	471.5	40	935.9	41	980.1	7
Bare ground	66.8	143	4.2	12	35.2	40	117.0	41	62.9	7
Canopy cover	115.9	143	4.9	12	9.2	40	341.9	41	49.7	7

6 Minimum Detectable Effect Sizes for Selected LCTA Variables for Multiple Installations

Data from 27 installations were used to evaluate the power of LCTA monitoring protocols across a range of ecotypes, installation sizes, and sampling intensities. Installations selected had at least 2 years of data available for processing and included Training and Doctrine Command (TRADOC), Army Materiel Command (AMC), Forces Command (FORSCOM), U.S. Army Europe (USAEUR), and National Guard Bureau (NGB) installations. Approximately 70 percent of the Army's land base is included in this study.

Minimum detectable effect sizes were estimated for disturbance, bare ground, and canopy cover data. These variables were selected because they are of primary interest to many installation personnel, frequently used in modeling efforts, common to all installations, and available from short-term and long-term surveys. The data sets used for the analyses were from the initial survey and next available survey year regardless of survey type. Because the variables of interest were available from both short-term and initial/long-term surveys, both types of surveys were used. When the first 2 years contained a large number of missing plots, the next available set of years was selected. Only plots with data for all variables for both years were used for the analyses, and only core plots were included in the analyses because the results were summaries of the whole installation. As a result of these restrictions, only two installations were analyzed with data from other than the first 2 years, and generally only a few plots per installation were not used because of missing data. Summaries of these variables were based on their presence or absence at 100 points along the LCTA line transect (Tazik et al. 1992); therefore, installation means are in terms of percent or number of transect points.

Figure 1 shows the relationship between the relative minimum detectable effect size and the installation mean for each of the three variables summarized. Relative minimum detectable effect size decreases with increasing abundance of the measured variable. Relative minimum detectable effect size was generally below 25 percent of the installation mean for these variables when the mean value was above

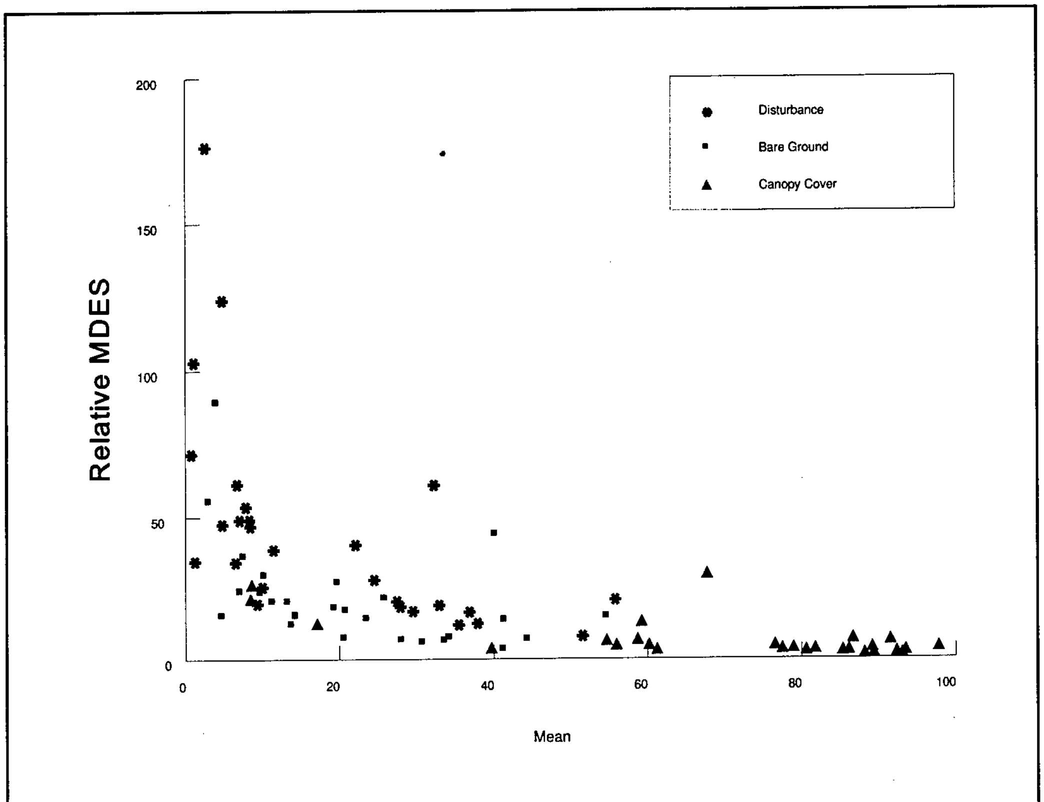

Figure 1. Relative minimum detectable effect size (MDES) for disturbance, bare ground, and canopy cover as a function of the installation mean.

20 percent. Relative minimum detectable effect sizes increased dramatically for installation means below 10 percent.

Figure 2 shows the relationship between the absolute minimum detectable effect size and the installation mean for each of the three variables summarized. Absolute minimum detectable effect sizes are generally below 10 percent for each variable across the range of installation means.

Concerns have frequently been expressed about the number of LCTA plots allocated per installation. These concerns include: too few plots allocated to adequately monitor the installation, too many plots for which insufficient time and funds are available for special use plots and other studies, and the arbitrary setting of a maximum of 200 plots due to implementation constraints. Figures 3 and 4 show the relationships between the relative and absolute minimum detectable effect sizes, respectively, and the number of plots per installation for disturbance, bare ground, and canopy cover estimates. Increases in sample size are associated with decreases in relative and absolute minimum detectable effect sizes. Considerable variation in

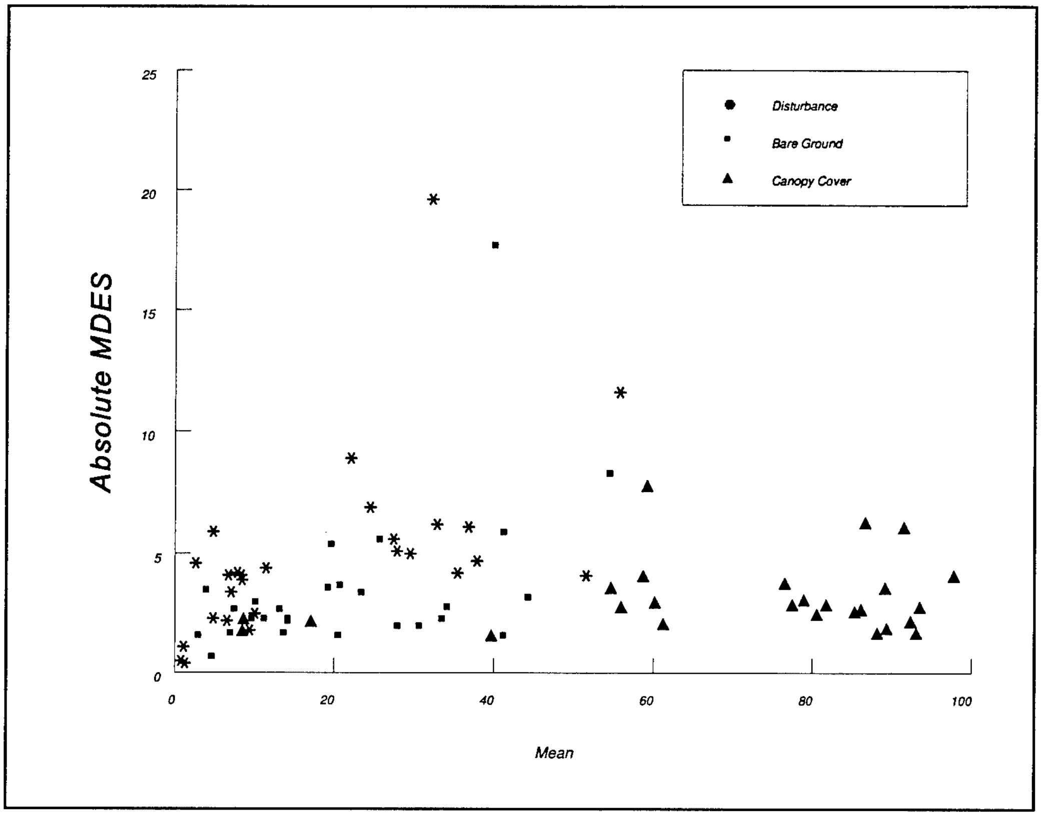

Figure 2. Absolute minimum detectable effect size (MDES) for disturbance, bare ground, and canopy cover as a function of the installation mean.

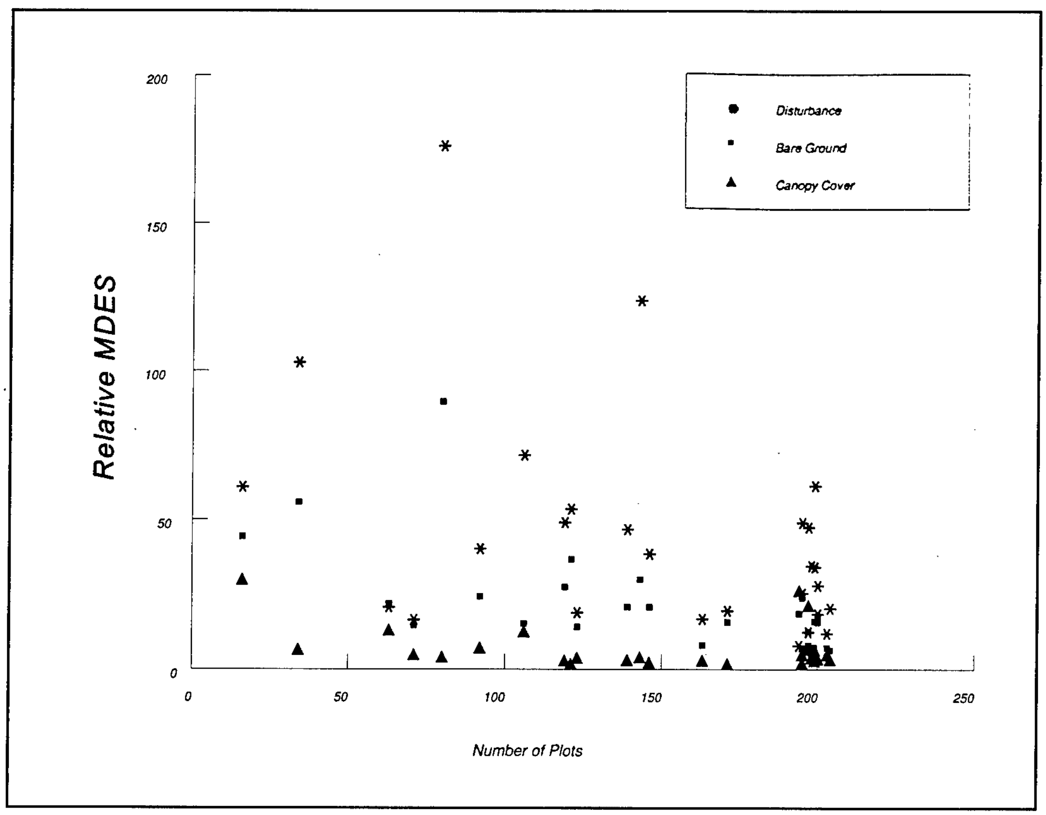

Figure 3. Relative minimum detectable effect size (MDES) for disturbance, bare ground, and canopy cover as a function of the number of plots sampled at the installation.

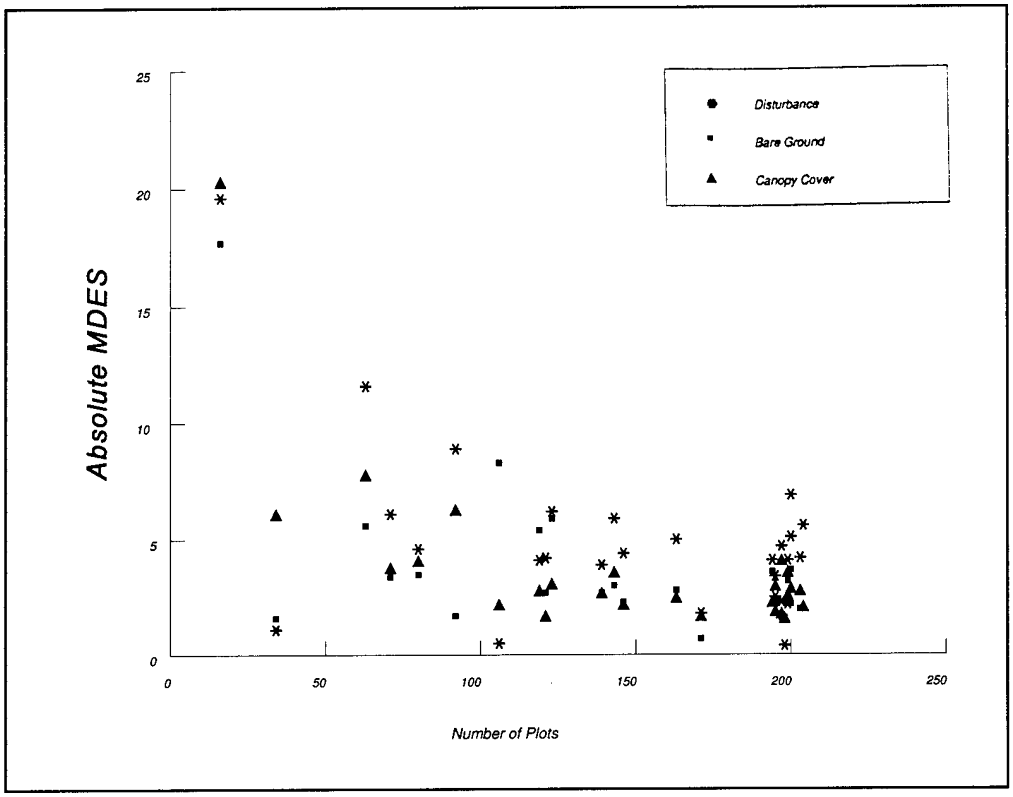

Figure 4. Absolute minimum detectable effect size (MDES) for disturbance, bare ground, and canopy cover as a function of the number of plots sampled at the installation.

both relative and absolute minimum detectable effect sizes exist between installations with similar numbers of plots. However, the variation in minimum detectable effect sizes was generally smaller for larger sample sizes.

Figures 5 and 6 show the relationships between relative and absolute minimum detectable effect sizes, respectively, and installation size for disturbance, bare ground, and canopy cover estimates. Although installation sizes are not evenly distributed over the range of installation sizes, minimum detectable effect sizes for larger installations were not consistently larger than effect sizes for smaller installations. In fact, some of the smaller installations had the largest minimum detectable effect sizes.

Another concern frequently expressed by installation personnel is the overall sample size relative to the size of the installation. LCTA monitoring protocols base the number of plots required on the size of the installation (Tazik et al. 1992). One plot per 500 acres is generally allocated. Limits in funding, manpower, and length of measurement season generally limit the maximum number of plots to 200. Consequently, the sampling intensity (number of plots per area) varies from installation

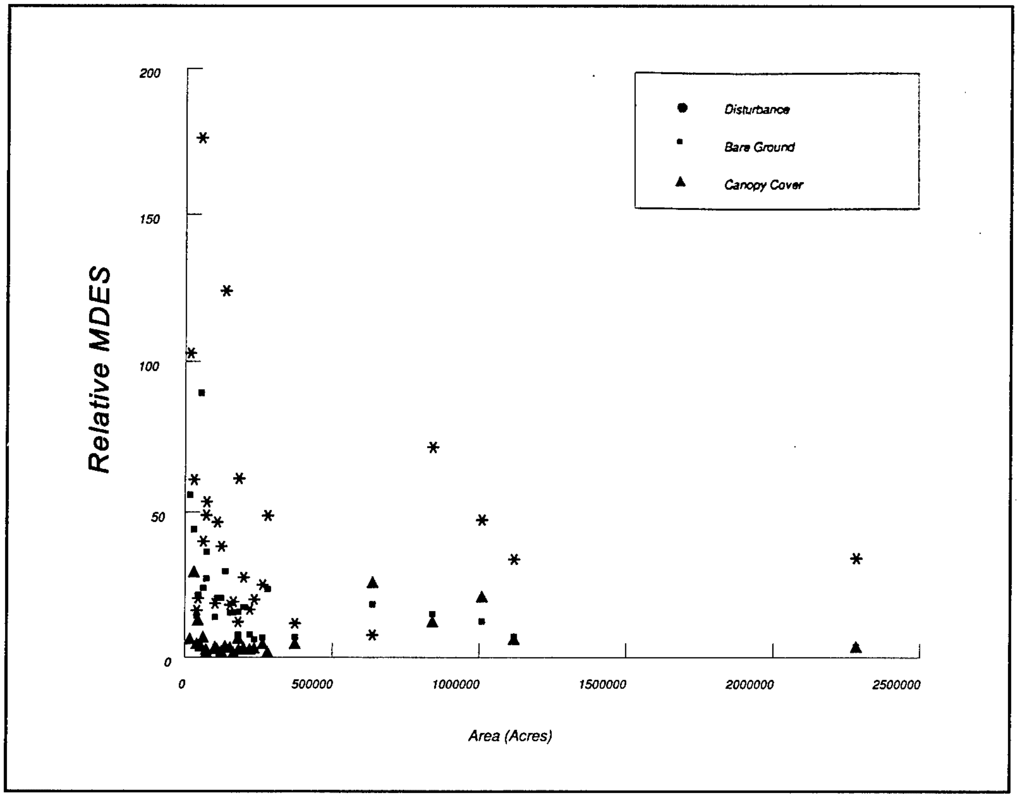

Figure 5. Relative minimum detectable effect size (MDES) for disturbance, bare ground, and canopy cover as a function of installation size.

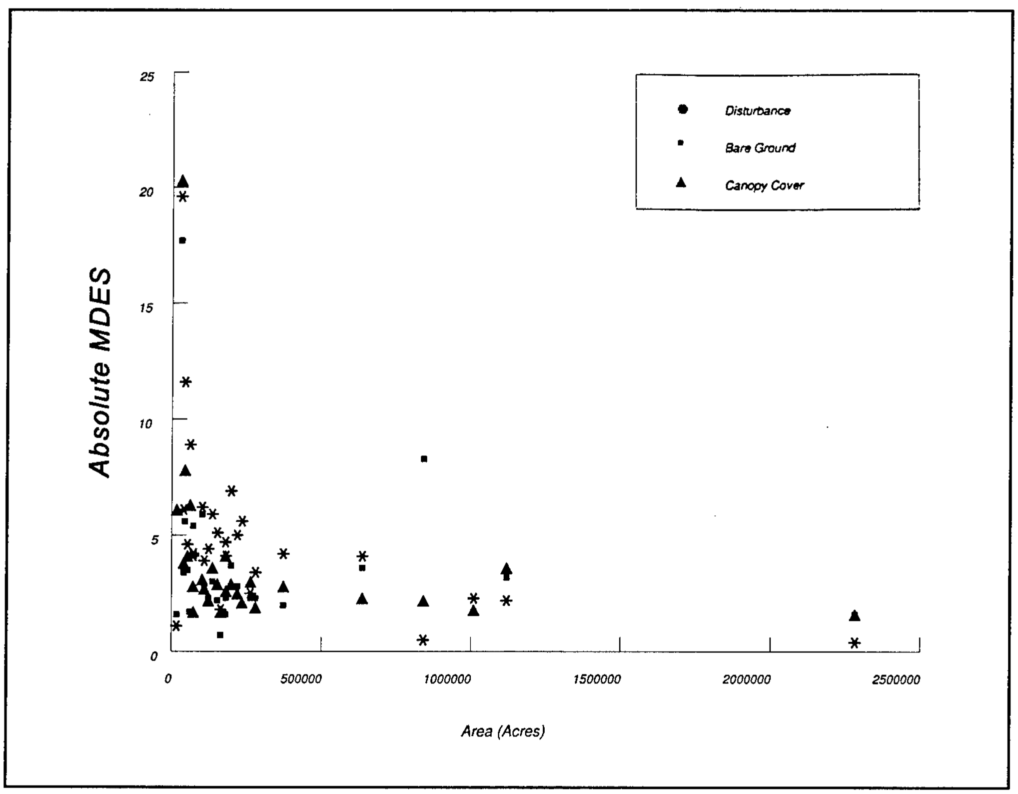

Figure 6. Absolute minimum detectable effect size (MDES) for disturbance, bare ground, and canopy cover as a function of installation size.

to installation. For the 27 installations used in this report, sampling intensities varied from approximately 1 plot per 500 acres to 1 plot per 11,500 acres. Figures 7 and 8 show the relationship between the relative and absolute minimum detectable effect sizes, respectively, and the sampling intensity. Minimum detectable effect sizes for installations with lower sampling intensities were not consistently larger than effect sizes for more intensively sampled installations. This data support the idea that it is more important to base plot allocation on the variance of the measured variable than strictly the size of the study area or even the sampling intensity.

Although the objectives, constraints, and methods of permanent sample plot monitoring programs vary considerably, the Army is considered to be ahead of other Federal agencies with more permanent field plots per acre than the other agencies (Shaw and Kowalski 1996). The following permanent plot survey intensities are provided for comparative purposes for this study. The U.S. Environmental Protection Agency (USEPA) Environmental Monitoring and Assessment Program (EMAP) uses approximately 1 plot per 250,000 acres (Messer et al. 1991). The Forest Health Monitoring (FHM) Survey jointly sponsored by the U.S. Forest Service (USFS), USEPA, Bureau of Land Management (BLM), Natural Resources Conservation Service (NRCS), Tennessee Valley Authority (TVA), and many state agencies uses a subset of the EMAP plots (Burkman and Hertel 1992). The National Resource Inventory (NRI) of the NRCS uses 300,000 primary sample units nationwide with three sample points per primary sample unit. The USFS Forest Inventory and Analysis (FIA) program uses 150,000 plots nationwide. The U.S. Department of Agriculture (USDA) Forest Service Southern Annual Forest Inventory System (SAFIS) averages 1 plot per 3500 acres in the southeast and 1 plot per 5000 acres in the midsouth. The National Wetlands Inventory (NWI) program of the U.S. Fish and Wildlife Service (USFWS) uses 3629 plots nationwide, each four square miles in size. The Queensland Forest Service's continuous forest inventory in Australia uses approximately 1 plot per 3000 acres (Beetson et al. 1992). The Swiss National Forest Inventory uses 1 plot per 250 acres (Kohl et al. 1995). The Leiria National Forest continuous forest inventory in Portugal uses 1 plot per 2.5 acres (Soares et al. 1995).

Previous data summaries reported in this section related the minimum detectable effect sizes for selected variables to sampling protocol concerns such as total number of plots, installation size, and sampling intensity. These summaries address whether LCTA protocols adequately monitor all installations involved in the program and whether summaries contrasting installations are comparable. However, it may be more important for the Army to monitor those installations at which the

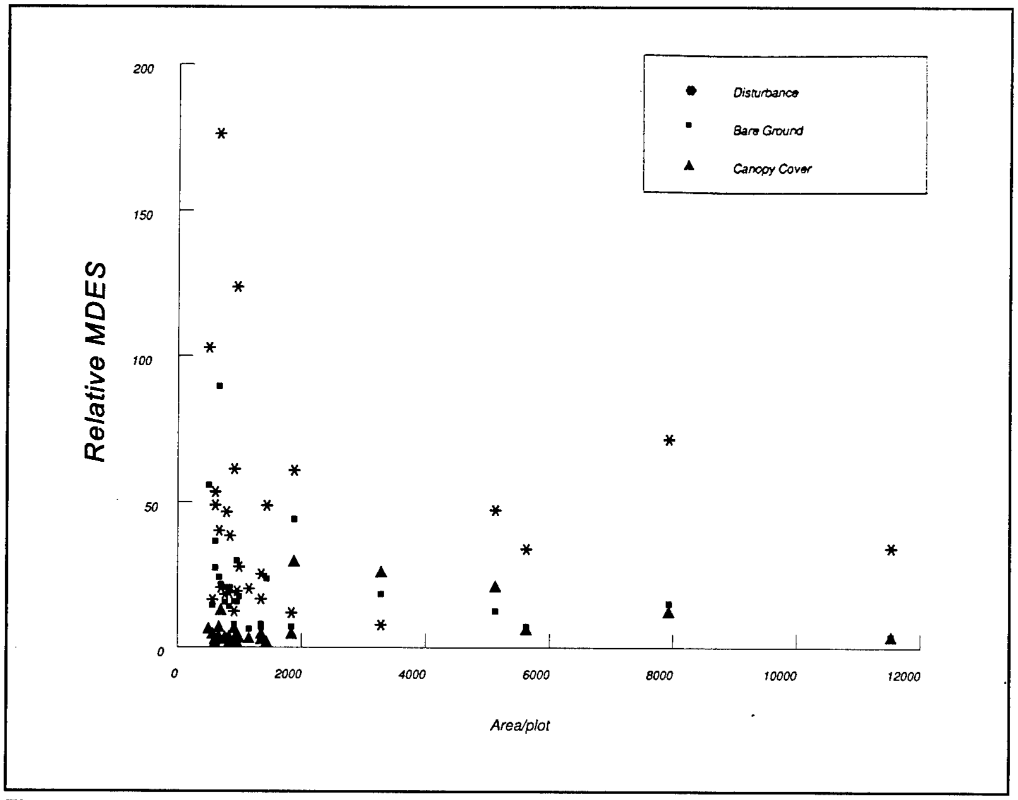

Figure 7. Relative minimum detectable effect size (MDES) for disturbance, bare ground, and canopy cover as a function of the average area represented per plot for an installation.

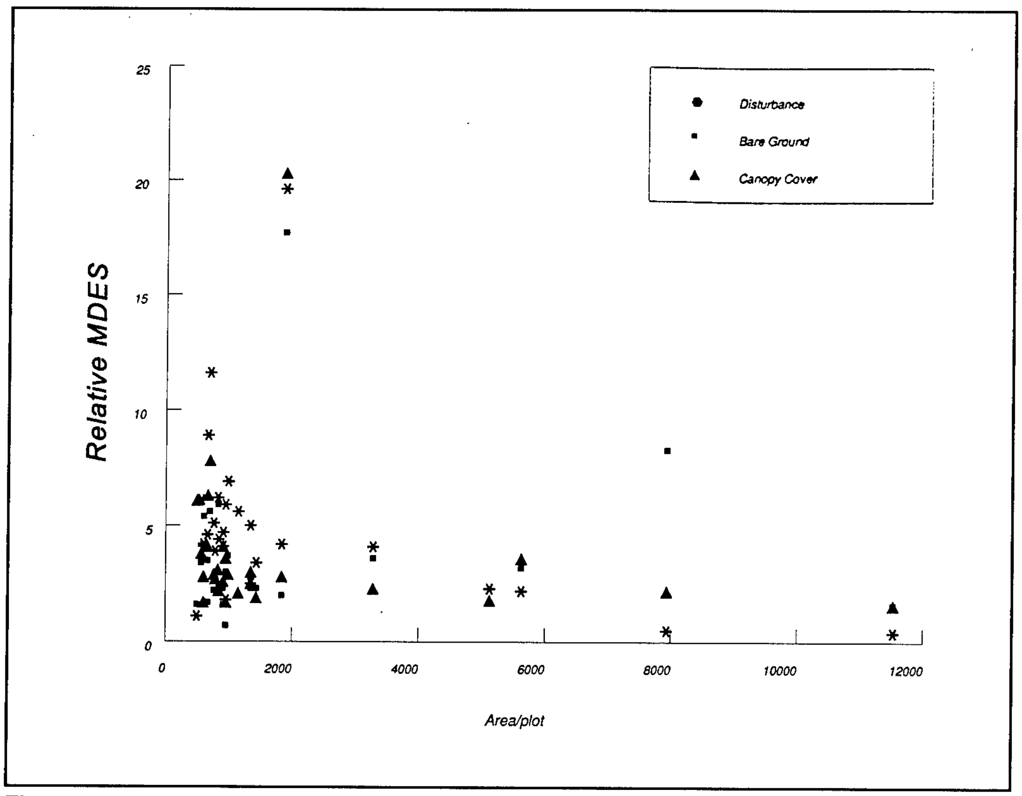

Figure 8. Absolute minimum detectable effect size (MDES) for disturbance, bare ground, and canopy cover as a function of the average area represented per plot for an installation.

greatest potential for change in resources exist. The ITAM program currently rates the priority of each installation involved with the ITAM program (U.S. Army 1996). Each installation is assigned to one of four prioritization categories based on a combination of installation size, mission, and environmental sensitivity to mission impacts. These categories define the relative importance of land management among installations. Category 1 represents the largest installations with the most critical training mission and greatest environmental sensitivity to missions. Category 2 represents large installations with important training missions and significant environmental sensitivities to missions. Category 3 represents smaller installations with training missions and some environmental sensitivity to mission. Category 4 represents extremely small installations with training missions and minimal environmental sensitivity to missions. Figures 9 and 10 show relative and absolute minimum detectable effect sizes, respectively, for disturbance, bare ground, and canopy cover by ITAM priority class rankings. On average, higher priority installations are sampled as well as or better than lower priority installations in terms of the minimum detectable effect sizes for disturbance, bare ground, and canopy cover. The variation in minimum detectable effect sizes between installations within a category was greater for Category 2 and 3 installations than the top priority installations.

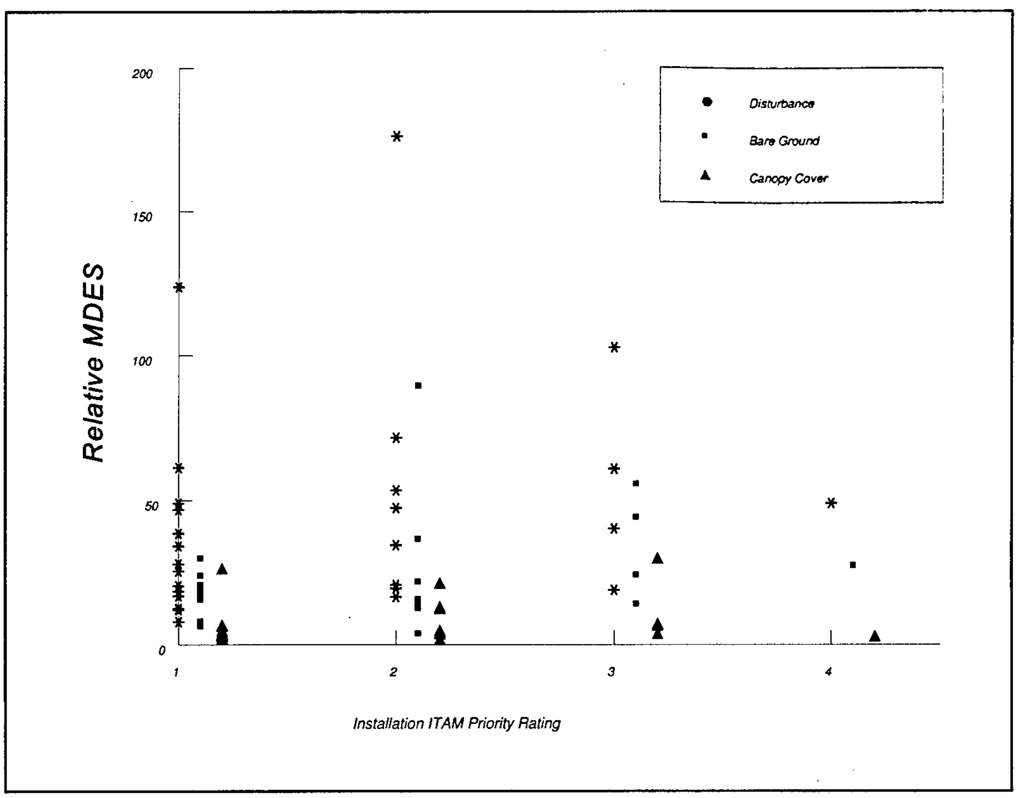

Figure 9. Relative minimum detectable effect size (MDES) for disturbance, bare ground, and canopy cover as a function of the ITAM priority rating.

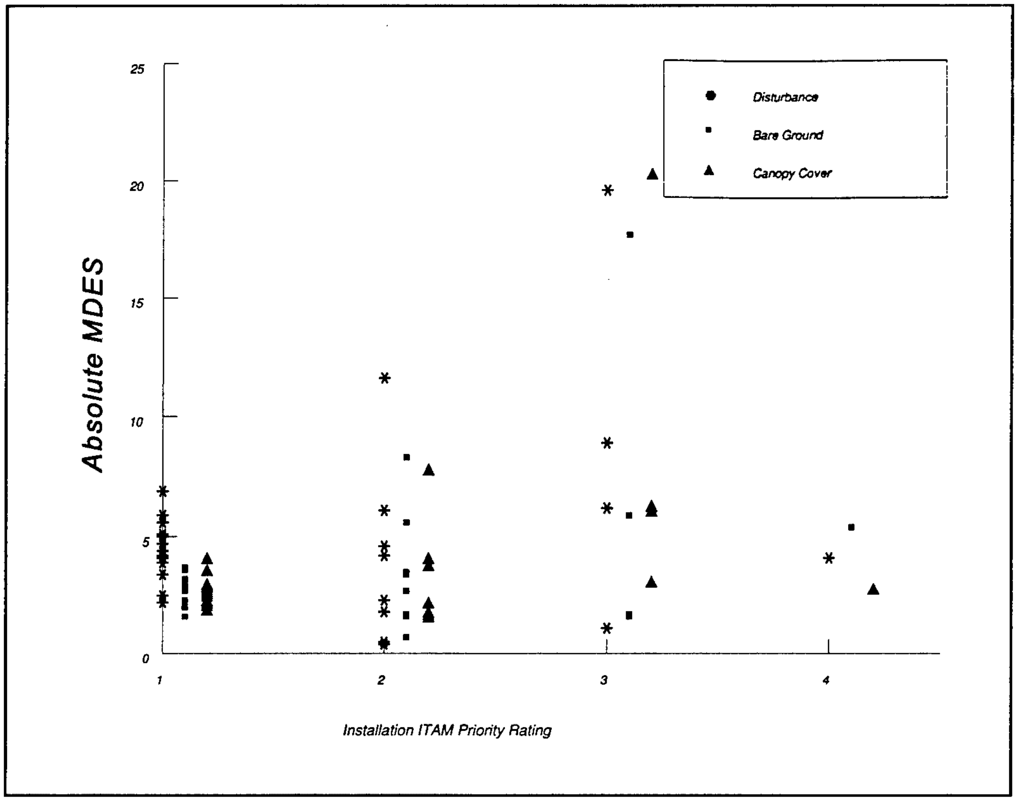

Figure 10. Absolute minimum detectable effect size (MDES) for disturbance, bare ground, and canopy cover as a function of the ITAM priority rating.

7 Conclusions

The first objective of this report was to demonstrate relatively simple techniques that can be used by installation personnel to evaluate the ability of the LCTA monitoring protocols to detect changes in installation natural resources. Power analysis was identified as a suitable technique that is relatively simple to use and that make use of existing data. The ability of the LCTA monitoring protocols to detect changes in resources was quantified in terms of minimum detectable effect sizes. Minimum detectable effect size is the smallest change in a variable that can be detected by the monitoring program with specified Type-I and Type-II error rates.

A comprehensive analyses of statistical power associated with the Fort Hood LCTA monitoring program demonstrated the consequences of changes in acceptable Type-I and Type-II error rates, test type (one-tailed vs. two-tailed), and the resource monitored. Minimum detectable effect sizes for specific variables ranged considerably from less than 5 percent of the mean to greater than 500 percent of the mean. Changes in acceptable error rates and type of test had a relatively small effect on minimum detectable effect sizes as compared to the selection of the variable monitored. Increasing acceptable error rates from 0.1 to 0.2 only resulted in a decrease in minimum detectable effect size of less than 20 percent for disturbance, bare ground, and canopy cover variables. Using one-tailed instead of two-tailed tests resulted in a decrease in minimum detectable effect sizes of less than 15 percent for disturbance, bare ground, and canopy cover variables. The effect of poststratification of LCTA data sets on minimum detectable effect sizes also was demonstrated. With few exceptions, poststratification (or data subsetting) increased minimum detectable effect sizes. Reductions in sample size more than offset any decreases in sample variance. Minimum detectable effect sizes for diverse ecotypes were contrasted for a range of variables. Although minimum detectable effect sizes varied between ecotypes, the trends among variables were fairly consistent across ecotypes.

The second objective of this report was to apply power analysis techniques to commonly used data summaries for a range of installations to quantify the ability of the LCTA monitoring protocols to detect changes in the installation natural resources. Minimum detectable effect sizes were estimated for 27 installations representing a range of installation sizes, sampling intensities, missions, and environmental conditions. For installation level summaries, 80 percent of the installations summarized could detect a relative change of 60, 27, and 7 percent of the mean in disturbance, bare ground, and canopy cover variables, respectively. Eighty percent of the installations summarized could also detect an absolute change of 6, 4, and 4 percent in disturbance, bare ground, and canopy cover, respectively. Minimum detectable effect sizes for larger installations, which often had lower sampling intensities (number of plots per area), were not consistently larger than smaller installation with higher sampling intensities. Higher priority installations had minimum detectable effect sizes that, on average, were as good as or better than lower priority installations.

Although the analyses in this report quantify the ability of the LCTA monitoring protocols to detect changes in resources, an assessment of the sufficiency of the protocols cannot be made. To determine whether the monitoring protocols meet management objectives requires additional information. Clearly defined monitoring objectives, translated in terms of monitored variables, and determinations of biologically significant change are required to determine sampling sufficiency. Management objectives and biologically significant change are likely to be installation specific, and their determination is beyond the scope of this project. However, the information and techniques in this report will assist land managers in assessing the sufficiency of the monitoring protocols to meet specified objectives which are based on installation, MACOM, and Department of the Army (DA) policy and guidance.

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